Perspective

Environmentally Sustainable Ironmaking: An Indonesian Perspective

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ABSTRACT

Indonesia is the country with the largest Gross Domestic Product (GDP) in the Association of Southeast Asian Nations (ASEAN) region. Recently, Indonesia has been intensively developing its infrastructure. This infrastructure development has caused Indonesia's iron and steel consumption to continue continuously. The rapid growth of infrastructure and transportation in Indonesia contributes to a significant increase in CO_2 emissions. Indonesia, as one of the countries to sign the Paris Agreement and COP21, should prepare for the development of a green and sustainable ironmaking sector. This article aims to offer a perspective on the iron and steel production process in Indonesia and the ASEAN region, while also proposing potential initiatives to develop an environmentally friendly and sustainable ironmaking process in Indonesia. This article will explain the position of iron and steel production in Indonesia within the ASEAN region, followed by a general explanation of ironmaking processes, such as blast furnaces, direct reduction iron, and the smelting reduction process. Lastly, this article will discuss the strategies for promoting environmentally sustainable ironmaking in Indonesia, including the utilization of biomass in ironmaking, the use of H_2/NH_3-based ironmaking, and the use of alternative raw materials for iron and steel manufacturing.

KEYWORDS: sustainable ironmaking; steelmaking; smelting; sustainable iron resources

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INTRODUCTION

In the ASEAN region, Indonesia is the country with the largest GDP. In 2020, Indonesia had an average GDP of 1.06 billion USD [1]. Given the size of its GDP, Indonesia is actively investing in infrastructure development.

This development has led to a continuous increase in Indonesia's iron and steel consumption. Steel is an important material for developing a country's infrastructure and for this reason, a nation's progress is closely correlated with its level of steel consumption and production. Despite the advances in material technology such as polymer materials, ceramics, composites, and non-ferrous metals, steel, particularly for structural applications, is still irreplaceable. Over the last 10 years, the amount of apparent steel use (ASU) in Indonesia has significantly increased. In 2010, Indonesia utilized approximately 10.7 million tons of ASU. By 2019, Indonesia's ASU almost doubled to 19.1 million tons [2]. In addition to increased steel consumption, Indonesia's crude steel production has also increased significantly. In 2010, Indonesia's crude steel production was about 3.6 million tons. By 2020, the country was able to produce about 9.3 million tons of crude steel. The turning point of the increment in Indonesian steel production occurred in 2014 with the start of the operation of Krakatau Posco, which has a production capacity of about 3 million tons. Indonesia now ranks as the 19th largest crude steel producer in the world [3], up from its 21st position in 2019. Within ASEAN, Indonesia ranks second to Vietnam, which produced up to 19.5 million tons of crude steel. Indonesia's increasing crude steel production is likely to meet the domestic steel demand. However, this increased production will also lead to an increase in CO_2 gas emissions. It is well known that the iron and steel industry contributes around 7%–9% of the total global CO_2 emissions [4]. As a result, the iron and steel industry is one of the largest industrial sources of CO_2 emissions [5]. To plan an ironmaking process that is environmentally sustainable, several indicators must be considered, including greenhouse gas emissions, energy consumption required, efficiency in the use of raw materials, and environmental management systems used [6]. Therefore, there are two main routes for producing iron and steel: the Blast Furnace-Basic Oxygen Furnace (BF-BOF) route and the Direct Reduction Iron-Electric Arc Furnace (DRI-EAF) route. The BF-BOF route is still the most widely used steel production route globally, because it is the most conventional technology and is known to have high productivity levels [2]. The BF-BOF route emits approximately 1.85 tons of CO_2 per ton of product, according to estimates. On the other hand, the DRI-EAF route emits about 0.97 tons of CO_2 per ton of product [7].

This article aims to provide an overview of the process of iron and steel making in Indonesia and the ASEAN region, as well as explore efforts that may be made to generate a process of ironmaking that is environmentally friendly and sustainable in Indonesia. According to the World Steel Association (2023), there are several sustainability criteria that apply to the steel production process, including reducing CO_2 emissions and increasing economic value distribution [8]. This paper primarily focuses on alternative technologies that could potentially assist Indonesia in developing a low-CO_2-emission ironmaking process. Furthermore, this paper explores alternative raw materials beyond iron ore, aiming to decrease the amount of imported iron ore and iron-bearing raw materials, thereby enhancing Indonesia's economic value distribution.

IRON AND STEEL STATISTICS IN THE ASEAN REGION

Figure 1 shows that, for the most part, countries in the ASEAN region have increased their crude steel production between 2016 and 2020. Vietnam still produces the highest amount of crude steel in the ASEAN region, with Indonesia coming in second, followed by Malaysia, Thailand, and the Philippines. Krakatau Steel began operating Indonesia's first iron and steel plant in 1970. Krakatau Steel uses DRI-EAF technology, with the main reactor for ironmaking being HyL III. In 2010, Indonesia's crude steel production continued to decrease.

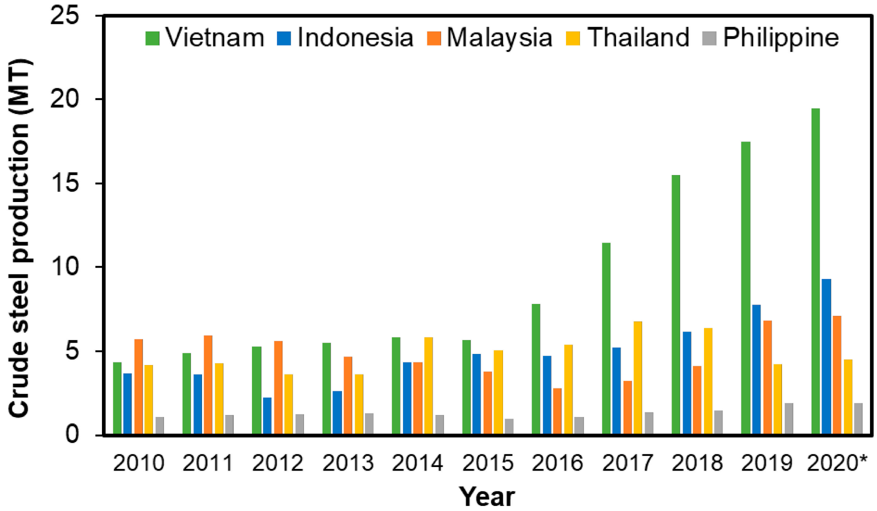

Figure 1. Crude steel production among ASEAN countries. Processed based on [1,2]. Note: * means estimated.

The decline in Indonesia's net export of steel from 2011 to 2013 was caused by the drop in global steel demand due to the crisis in Europe and the US. On the other hand, the large volume of imported steel, especially from China, which offers a more competitive price, also caused the decline in steel net exports in 2018. The increase in Indonesia's steel imports in 2018 was also due to the Indonesian government's extensive infrastructure development projects.

The significant increase in crude steel production began in 2014, when Krakatau Posco operated the first blast furnace technology in Indonesia. Furthermore, the trend of enhanced production of crude steel in Indonesia aligns with the increase in the production capacity of Krakatau Posco; thus, for the next few years, Indonesia's crude steel production will be dependent on Krakatau Posco steel production. Currently, Krakatau Posco's steel production capacity is around 3 million tons and will increase to 10 million tons by 2025.

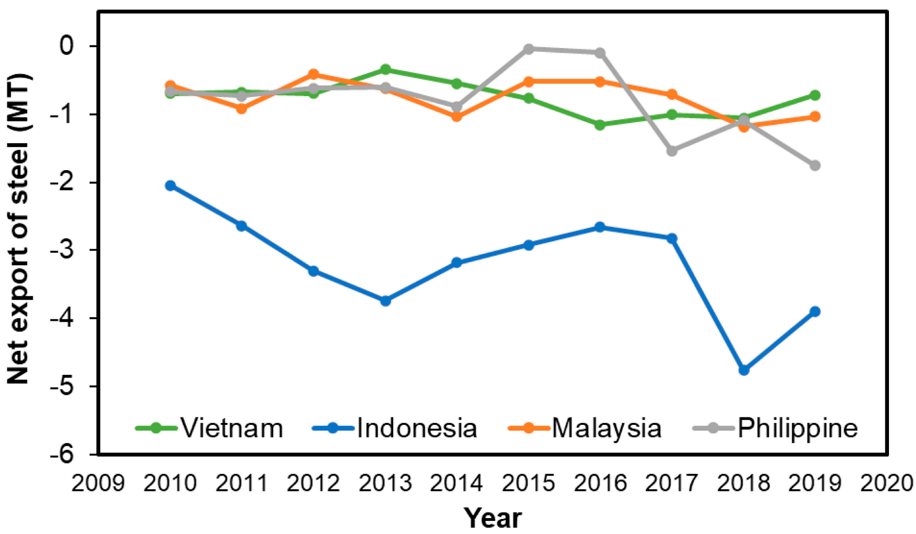

Figure 2. Net export of steel among ASEAN Country. Processed based on [2].

In Malaysia, steel production uses blast furnaces and direct reduced iron technology [9]. Steel production in Malaysia started in the late 1960s with the operation of Malayawata steel, which used blast furnaces. Around 1980, the Perwaja Trengganu plant started to operate using the first DRI-EAF route in Malaysia [10]. Several low-grade iron ore mines in Malaysia, including those in Trengganu, Johor, Perak, and Pahang, are utilized to produce steel [11]. In addition, Malaysian steel mills also import high-grade iron ore from several countries, such as Chile, Brazil, Mexico, and Bahrain [12]. In Thailand, steel was initially produced using both BF-BOF and DRI-EAF routes. However, current steel production in Thailand focuses only on the EAF process, which utilizes steel scrap [13,14]. As a result, crude steel in Thailand is exclusively produced through the EAF process. This is one of the causes of insufficient steel supply. Most of Thailand's iron and steel industries are located in the southeast and Bang Saphan. The Philippines has approximately 300 million tons of iron ore reserves. The Philippine steel industry began in 1952 with the construction of the Electric Arc Furnace facility. In its development, the Philippine government initiated the development of an integrated iron and steel mill in 1977 with the establishment of the Philippine Sinter Corporation, which supplies sinter for blast furnace operations in Japan [15].

In contrast, Vietnam established its first iron and steel industry in the 1960s with the Thai Nguyen Iron and Steel Complex establishment [16]. Then, in 1986, Vietnam established the Doi Moi policy to transform Vietnam's economic policy into a "socialist-oriented market economy" [17]. Vietnam itself appeared to accelerate steel production in 2005 [18]. At that point in time, Vietnam had established an integrated steel plant with a small capacity. In 2007, Vietnam joined the World Trade Organization (WTO), opening up great opportunities for investors to invest [16]. From 2007 to 2017, Vietnam's production of crude steel experienced significant acceleration due to the establishment of large-scale integrated steel mills that specialized in the ironmaking, steelmaking, and hot rolling processes. Observing the growth of Vietnam's iron and steel industry, Indonesia could potentially observe and adopt similar strategies to accelerate its own development. Moreover, Indonesia currently has the lowest net steel exports in the ASEAN region, according to figures shown in Figure 2.

GENERAL IRONMAKING PROCESS

Blast Furnace (BF) Process

The process of making iron through BF is still the most widely used. The BF, a vertical reactor, facilitates the smelting of iron ore. Before entering the BF, the iron ore fines typically undergo a sintering process, which agglomerates the ore at a semi-molten temperature [19]. The BF receives sinter, coke, and flux. Equations (1)–(4) show some of the main reduction reactions in the blast furnace process [20,21]. Equations (1) and (3) indicate that some iron oxide reduction reactions in the blast furnace process are classified as exothermic. Energy is obtained from coke combustion. At the same time, the coke will also be gasified as per equations (5) and (6) into CO and H_2 gases, which are useful as reductants. In Indonesia, PT. Krakatau Posco uses a BF to produce iron.

$$3\mathrm{Fe_2O_{3(s)}} + \mathrm{CO}_{(g)} \rightarrow 2\mathrm{Fe_3O_{4(s)}} + \mathrm{CO}_{2(g)}, \Delta H^0_{823\ K} = -29.6\ \mathrm{kJ}, \Delta G^0_{823\ K} = -78.42\ \mathrm{kJ} \tag{1}$$

$$\mathrm{Fe_3O_{4(s)}} + \mathrm{CO}_{(g)} \rightarrow 3\mathrm{FeO}_{(s)} + \mathrm{CO}_{2(g)}, \Delta H^0_{823\ K} = 22.29\ \mathrm{kJ}, \Delta G^0_{823\ K} = -0.35\ \mathrm{kJ} \tag{2}$$

$$\mathrm{FeO}_{(s)} + \mathrm{CO}_{(g)} \rightarrow \mathrm{Fe}_{(s)} + \mathrm{CO}_{2(g)}, \Delta H^0_{823\ K} = -20.99\ \mathrm{kJ}, \Delta G^0_{823\ K} = -0.241\ \mathrm{kJ} \tag{3}$$

$$\mathrm{FeO}_{(s)} + \mathrm{C}_{(g)} \rightarrow \mathrm{Fe}_{(s)} + \mathrm{CO}_{(g)}, \Delta H^0_{1023\ K} = 151.68\ \mathrm{kJ}, \Delta G^0_{1023\ K} = -3.86\ \mathrm{kJ} \tag{4}$$

$$\mathrm{C}_{(s)} + \mathrm{CO}_{2(g)} \rightarrow 2\mathrm{CO}_{(g)}, \Delta H^0_{1023\ K} = 170.43\ \mathrm{kJ}, \Delta G^0_{1023\ K} = -8.47\ \mathrm{kJ} \tag{5}$$

$$\mathrm{C}_{(s)} + \mathrm{H_2O}_{(g)} \rightarrow \mathrm{H}_{2(g)} + \mathrm{CO}_{(g)}, \Delta H^0_{1023\ K} = 135.89\ \mathrm{kJ}, \Delta G^0_{1023\ K} = -10.87\ \mathrm{kJ} \tag{6}$$

Direct Reduction Iron (DRI) Process

The Direct Reduction Iron process is an alternative to the BF process. The DRI process operates at a temperature below the melting point of the material fed into the reactor. To reduce iron oxide to metallic iron, a reducing agent in the form of CO gas (equations (1)–(3)) and H_2 (equations (7) and (8)) can be applied [22]. The products of the DRI process include sponge iron or direct reduced iron, and hot briquette iron.

$$3\mathrm{Fe_2O_{3(s)}} + \mathrm{H}_{2(g)} \rightarrow 2\mathrm{Fe_3O_{4(s)}} + \mathrm{H_2O}_{(g)}, \Delta H^0_{823\ K} = 6.98\ \mathrm{kJ}, \Delta G^0_{823\ K} = -69.52\ \mathrm{kJ} \tag{7}$$

$$\mathrm{Fe_3O_{4(s)}} + \mathrm{H}_{2(g)} \rightarrow 3\mathrm{FeO}_{(s)} + \mathrm{H_2O}_{(g)}, \Delta H^0_{1023\ K} = 51.27\ \mathrm{kJ}, \Delta G^0_{1023\ K} = -2.42\ \mathrm{kJ} \tag{8}$$

The process of making steel through the DRI-EAF route contributes to about 26.3% of all steelmaking processes worldwide, while the remaining 73.2% still apply the BF-BOF route [2]. In the past 10 years, Indonesia's DRI products have tended to decline. In fact, in 2016, Indonesian-produced no DRI products. Then, between 2017 and 2019, Indonesia's DRI production fluctuated, although the output was still relatively insignificant compared to pig iron. As shown in Figure 3, Indonesia's DRI production was only about 120 thousand tons, or 3.97%, while pig iron accounted for 96.03%. In Indonesia itself, the process of making iron using DRI is carried out by PT. Krakatau Steel.

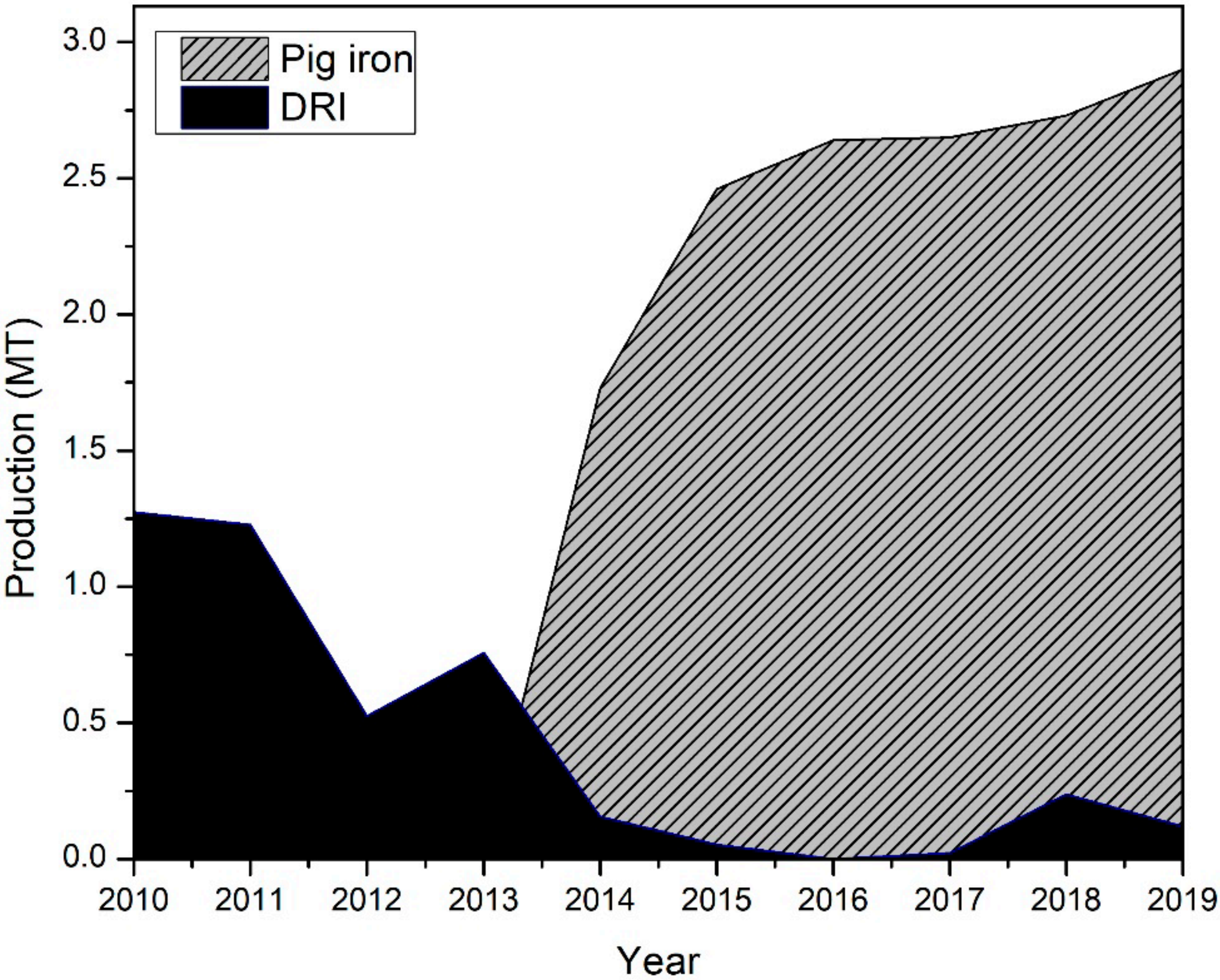

Figure 3. Comparison of Pig Iron and DRI products produced in Indonesia between 2010 and 2019. Processed based on [2].

Aside from blast furnaces and conventional DRI technology, smelting reduction technology offers an alternative to the ironmaking manufacturing process. Smelting reduction does not use metallurgical coke and pre-agglomerated materials (such as sinters and/or pellets), and this technology is able to minimize air pollution [23]. Smelting reduction technology uses a pre-reduction process for iron oxide, followed by a smelting process for slag and hot metal separation. Several technologies that practice the principle of smelting reduction include FINEX [24], COREX [25], HIsarna [26], and others [27].

TECHNOLOGICAL ALTERNATIVES TO ACHIEVE ENVIRONMENTALLY SUSTAINABLE IRONMAKING IN INDONESIA

Use of Biomass

According to the Life Cycle Assessment (LCA) study, using biomass can help mitigate CO_2 emissions compared to using fossil fuels such as coal or coke [28]. Additionally, the use of biomass in ironmaking is relatively easier to implement due to its application, which doesn't require a major overhaul of existing plants and has a comparatively lower investment cost [29]. Applying biomass to the BF-BOF route, the world's largest steel-making route and the largest source of CO_2 emissions in the steel-making sector, will enhance its use. Estimates suggest that applying biomass to the BF-BOF route can reduce CO_2 emissions by approximately 54% [30,31].

Charcoal is a biomass that can be used to substitute fuel on the BF-BOF route. Furthermore, biomass can partially replace coke during the coke-making, sintering, and blast furnace stages [31]. Brazil and Paraguay have implemented the use of charcoal as fuels and reducing agents [32]. However, the mechanical properties of charcoal limit the size of blast furnaces suitable for its use, resulting in a lower productivity per unit of its reactor compared to a coke blast furnace. Therefore, another method of using charcoal in blast furnace operations involves injecting it into the furnace through a tuyere [33–35]. Indonesia has enormous biomass potential, estimates suggesting that the country can produce approximately 146.7 million tons of biomass annually [36]. Therefore, in the future, fuel substitution and reducing agents applied to biomass in Indonesia's iron and steel manufacturing plants present a promising opportunity.

Indonesia also has a large potential for charcoal production. As the world's largest exporter of wood charcoal, Indonesia has an export value of around 400 million USD in 2022, contributing around 23.68% of global wood charcoal exports. Using charcoal as a reductant in iron making is one way to reduce the use of fossil fuels and reductants in iron making in Indonesia. Figure 4 demonstrates that Indonesia's wood charcoal production is abundant because the net export volume value is positive. Furthermore, from 2019 to 2022, Indonesia contributed between 19 and 24% of the world's wood charcoal trade and consistently ranked as the top global exporter.

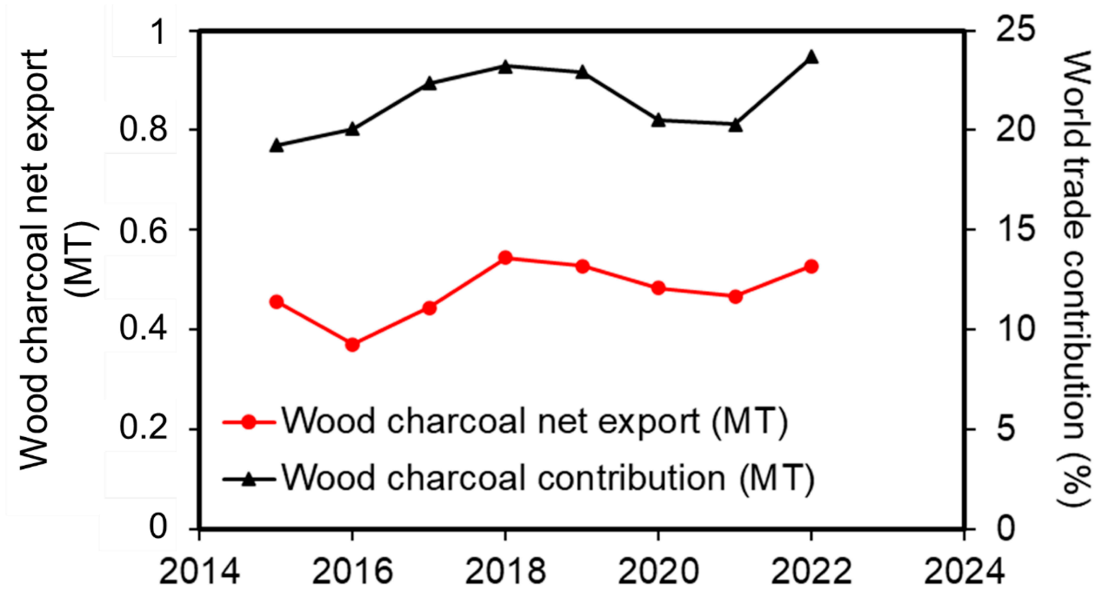

Figure 4. Data on Indonesia's net wood charcoal export volume and contribution to the world wood charcoal trade. Data processed from World Integrated Trade Solutions, World Bank [37].

Hydrogen Ironmaking

The use of hydrogen gas in the ironmaking process is another option to reduce CO_2 emissions in the iron and steel-making sector. H_2 gas can replace the role of C or CO_2 in reducing iron oxide. The iron oxide reduction reaction with H_2 will produce environmentally friendly water vapor. Equations (7) and (8) show the reduction of iron oxide by H_2.

As before, since the majority of iron- and steelmaking processes in the world use the BF-BOF route, significantly reducing world CO_2 emissions requires modification of this route. The modification involves the injection of H_2 gas through the tuyere into the blast furnace. Injecting H_2 into the blast furnace at 27.5 kg/THM as an additional gas can potentially reduce about 21.4% of CO_2 gas emissions [38]. However, the blast furnace can only accommodate a limited amount of H_2 gas injection. At some point, excessive H_2 gas injection will cause further endothermic reactions. The main reaction is shown in equation (9) [39]. The reaction described above will have an effect on the blast furnace temperature profile, particularly in the stack and upper regions.

$$\mathrm{CO}_{2(g)} + \mathrm{H}_{2(g)} \rightarrow \mathrm{CO}_{(g)} + \mathrm{H}_2\mathrm{O}_{(g)}, \Delta H^0_{1123\,K} = 33.56\ \mathrm{kJ}, \Delta G^0_{1123\,K} = -0.69\ \mathrm{kJ} \tag{9}$$

Currently, Indonesia is actively developing a green H_2 production facility with a design capacity of 51 tons per year through PT. Perusahaan Listrik Negara. However, the short-term plan for green H_2 will focus more on the transportation sector. Additionally, the plan to construct H_2 production facilities will be further developed in the future. For this reason, the utilization of H_2 for the iron-making process in Indonesia also opens up opportunities.

Ironmaking Using Ammonia

An environmentally friendly alternative for the ironmaking process is the utilization of ammonia gas (NH_3) as a reducing agent [40–42]. When compared to H_2, NH_3 has advantages in terms of ease of handling and cost. The ironmaking process using ammonia gas involves the direct reduction of iron oxide to ferrous metal as well as the indirect reduction of iron oxide using H_2, which is a decomposition product of NH_3 due to heating. In contrast to C/CO-based reduction, iron oxide reduction using ammonia produces only H_2O gas as a byproduct. Therefore, the ironmaking process using NH_3 does not emit any direct CO_2. Furthermore, experimental studies indicate that the reduction process of iron oxide using NH_3 does not produce NO_x emissions [40,42]. Considering that Indonesia is one of the top five global producers and exporters of ammonia gas [43], the ironmaking process utilizing NH_3 in Indonesia will be an attractive alternative in the future. However, Indonesia's current ammonia production mostly uses conventional processes and emits large amounts of CO_2. In the next few years, Indonesia will also build a green ammonia production facility that can be used for the ironmaking process. Nevertheless, in the short term, Indonesia's NH_3 production will be focused on supplying the fertilizer industry. Therefore, iron production using NH3 in Indonesia is more feasible as a long-term option.

Alternative Raw Materials

Alternative raw materials for iron and steelmaking process can be separated into two types. The first is scrap, while the second is a source of iron minerals other than iron hematite (Fe_2O_3) and magnetite (Fe_3O_4). The recycling of steel scrap plays a significant role in the steelmaking process, contributing about 24% of global steel production. The process of making steel from scrap is still relatively more prevalent than the DRI process, which accounts for about 5% of global steel production [44]. The recycling process of steel scrap, known as secondary production of steel can be integrated into both the BOF and EAF processes [45]. The use of steel scrap can also reduce approximately 1.5 kg of CO_2 per 1 kg of processed scrap [45]. However, because the type and composition of scrap can vary greatly, it is necessary to make adjustments during the recycling process. Therefore, its use in both BOF and EAF processes also has limitations. About 60 steel companies in Indonesia, with a total capacity of about 9 million tons per year, require scrap steel. Of this large percentage, around 60%–70% still rely on scrap imports [46].

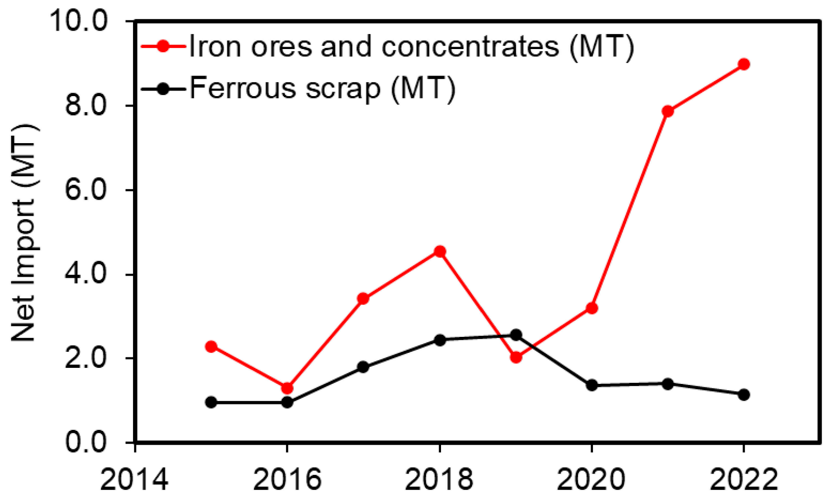

Figure 5. Net import of iron ore, concentrate, and ferrous scrap in Indonesia. Data processed from World Integrated Trade Solutions, World Bank [37].

Figure 5 illustrates the pattern of Indonesia's net import of iron ore, concentrate, and scrap. Figure 5 indicates that Indonesia continues to rely on imports of iron ore, as well as concentrate and scrap, to fulfill its domestic requirements. Iron ore and concentrates imported from Indonesia are mostly used by ironmaking plants such as PT. Krakatau Steel and PT. Krakatau POSCO while scrap is used by many small and medium steelmaking plants, which are far more numerous than ironmaking plants. These small mills typically focus on melting processes without smelting. Thus, based on their facilities, the use of scrap in Indonesia has more potential. It can also help small and medium enterprises in the steelmaking field become more developed. However, Indonesia still manages steel scrap separately, lacking centralization and a reliable and up-to-date national scrap data source. Given Indonesia's high national steel consumption, it should also have a significant amount of scrap. Therefore, enhancing standards and advanced scrap governance should be the first step. Australia can serve as a pilot country for scrap governance [47]. Furthermore, given that numerous national steel industries rely on scrap steel, there is a need to restrict scrap export regulations. This restriction may have been imposed because Indonesia's scrap exports decreased after 2019.

In addition to scrap steel, iron sand is an alternative raw material for iron production. Indonesia has abundant potential for iron sand, which is about 2.121 MT [48,49]. Besides iron, iron sand also contains titanium oxide (TiO_2), a high-value mineral [50,51]. TiO_2 is one of the important materials for the energy transition because it can be utilized in the process of making solar cells and batteries. In order to fully harness the potential of iron sand, Indonesia will require appropriate processing technology for iron sand over time. This technology should also be environmentally friendly, such as smelting reduction technology, which eliminates the need for an agglomeration process.

Table 1. Summary of technology alternatives for sustainable ironmaking in Indonesia.

Technology alternatives	**Pros**	**Cons**	**Related sustainability indicators**
Biomass	Able to reduce dependence on fossil-based reductants. Indonesia's biomass (wood charcoal) production is relatively ready, as evidenced by the size of Indonesia's wood charcoal exports abroad.	It still emits direct CO_2. Need to harvest wood to avoid deforestation and reduction of existing carbon stock.	Reduction of CO_2 emissions.
Iron sand as iron-bearing raw material	To address Indonesia's difficulty in finding domestic high-grade iron ore.	A more detailed concept study is needed in selecting a suitable technology for ironmaking using iron sand.	Reduction of CO_2 emissions.
Hydrogen ironmaking	Able to reduce dependence on fossil-based reductants. Does not produce direct CO_2 emissions.	The reduction reaction is endothermic. Green hydrogen production facilities in Indonesia that are intended for the non-transportation sector are still not ready in the near future.	Reduction of CO_2 emissions.
Ironmaking using ammonia	Able to reduce dependence on fossil-based reductants. Does not produce direct CO_2 emissions.	Reduction reaction is endothermic. Green ammonia production facilities in Indonesia that are intended for the non-fertilizer sector are still not ready in the near future.	Increasing economic value distributed.

Table 1 shows a summary of alternatives that can be applied to create sustainable ironmaking in Indonesia. Based on the summary provided in Table 1, the short-term alternative technology for sustainable ironmaking in Indonesia involves the use of biomass-based reductant, specifically wood charcoal, in conjunction with iron sand as the iron-bearing material. This is an interesting topic of experimental research to be conducted in the near future in Indonesia. Furthermore, once green H_2 and NH_3 production facilities in Indonesia are operational, then H_2 and NH_3 ironmaking can be a long-term solution.

Certainly, these are generalized conclusions that still require in-depth analysis of the various options available. Nevertheless, this is an insight for the formulation of a roadmap for research and development in Indonesia's iron and steel sector. In addition, the utilization of Indonesian iron sand needs to be carefully studied. A trade-off analysis needs to be conducted by considering process, economic, environmental, and ecological aspects. Thus, the exploitative use of iron sand that damages the environment and ecology can be minimized and even avoided.

CONCLUSIONS

Indonesia's steel consumption, which continues to increase each year, presents both a challenge and an opportunity to generate an environmentally friendly and sustainable national steelmaking process that contributes to circular economy in the iron and steel sector. Over time, the selection and/or modification of national iron and steel manufacturing technology must take into account the CO_2 emissions generated. Currently, a number of technologies offer relatively low CO_2 emissions in iron and steel production, including smelting reduction technology, modifying blast furnaces to use fuel or biomass injectants, hydrogen or NH_3, and iron oxide electrolysis processes. Indonesia's high demand for steel scrap presents an opportunity to form a centralized steel scrap governance system with accurate and real-time data sources. Additionally, the processing of Indonesian iron sand presents a promising alternative source of iron. In general, considering Indonesia's rich potential in iron sand, processing through DRI and smelting reduction technologies, coupled with the partial substitution of fossil reducing agents using NH_3/H_2/biomass, is an attractive option. However, a detailed study of the economic and technical feasibility, as well as a life cycle assessment, needs to be conducted at a later stage. In summary, in the short term, the use of biomass (wood charcoal) and the utilization of iron sand can be a solution to create sustainable ironmaking in Indonesia. Furthermore, the use of hydrogen and ammonia in ironmaking can reduce CO_2 emissions even further in the long run. These short- and long-term solutions can help Indonesia meet sustainability targets in terms of reducing CO_2 emissions and increasing distributed economic value.

DATA AVAILABILITY

The dataset of the study is available from the authors upon reasonable request.

AUTHOR CONTRIBUTIONS

Conceptualization, SP and FAb; Methodology, SP and YS; Software, FAr; Validation, SP, YS, FAr, and FAb; Formal Analysis, SP and FAb; Investigation, SP and FAb; Resources, SP; Data Curation, FAr and FAb; Writing—Original Draft Preparation, SP and FAb; Writing—Review &

Editing, SP, YS, FAr, and FAb; Visualization, YS and FAb; Supervision, SP; Project Administration, SP; Funding Acquisition, SP.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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